Doctoral Dissertation
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Elastic smart meta-devices

Bio-inspired mechanical metamaterials for in materia signal processing

By

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Abstract

The rise in popularity of artificial intelligence, together with the trend in the integration of sensors and processors in everyday devices, is inherently tied to an exponential growth of the requirements related to battery and memory. This questions the compatibility of current traditional hardware based on Von Neumann architectures with the future demands of the industry. Near-sensor and in-sensor computing seem promising approaches to address these issues in devices for the Internet of Things: the information is processed in proximity to or inside the sensor itself, without converting it into digital signal. In the field of elasticity, waves propagating in a medium contain information regarding their source. Being able to extract and process this information without the need for electronic components results in major advantages in application fields that require low battery consumption. This thesis focuses on the design and development of advanced elastic metamaterials capable of performing in-materia signal processing. In-materia computation leverages the physical properties of materials to process information directly within the material itself, reducing the complexity of the signal readout performed with traditional electronic circuits. These metamaterials serve as both processors and memory, enabling efficient signal processing, data storage, and decision-making. The research investigates innovative structures, including a Gradient Index Phononic Crystal (GRIN PC) for elastic wave focusing and imaging of sources and defects, mass-spring systems with non-local coupling for wave localization via topologically protected states, and spiral resonators inspired by biological systems for frequency-selective response and speech recognition preprocessing. Light-responsive metamaterials are also explored, allowing remote control of mechanical properties with the possibility of tuning the device response over time. These devices mimic the adaptive efficiency of biological systems, offering versatile applications in the field of the Internet of Things, being compatible with strict requirements in terms of battery life and memory availability.